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Applications Of Robotics In Prosthodontics – A Review

S. Sreelekshmi

Kurian Varghese

Joshy P Abraham

Jaysa J. J.

Azzezia College of Dental Science and Research,
Kerala University of Health Sciences, Meeyannor, Kollam,
Kerala, India

***Abstract:** Application of robots for reducing the manual effort and increasing the accuracy of procedures are gaining momentum in various medical fields including dentistry. This article reviews the applications and progress so far of the use of robots in prosthodontics. Robotic interventions in prosthodontics are mainly for designing and manufacturing of complete dentures and for assisting in dental implantology surgical procedures. In both cases, great progress has been achieved, helping to obtain higher level of accuracy in the procedures with high success rates. The time required to complete each procedures are considerably reduced with the use of robots. But such sophisticated and specially made robots for various prosthodontic treatments have to be used under the strict supervision of an expert dentist. There's no substitute for expert skill and clinical judgment.*

***Keywords:** Robotics, Prosthodontics, Implantology robots, Yomi system*

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I. INTRODUCTION

Robots are human innovations to reduce manual efforts in hazardous working environments, to increase the accuracy and precision of the work being carried out, and to reduce manual labour. Robotics is the interdisciplinary branch of engineering and science that includes mechanical engineering, electrical engineering, computer science, and others. Robotics deals with the design, development, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing. Following the developments in industrial robot technology, robotics have found its way into the medical field and is used in a range of surgical disciplines including applications in dentistry.

Robotic systems are not intended as replacements for human doctors, but rather as smart surgical tools. They help to increase the precision, quality and safety of surgical procedures (Lea et al. 1995). Their most valuable function may be their capacity to create an information link from preoperative surgical plans to the surgical arena. The first documented case of a robot assisted surgical procedure was in 1985 when the Programmable Universal Manipulation Arm (PUMA 560) robotic system was used in a neurosurgical biopsy (Lanfranco et al. 2004). The success of PUMA 560 offered greater acumen for the use of such robotic systems for minimally invasive surgical procedures. In 1988, the same PUMA system was used to perform a robotic surgery - transurethral resection. In 1994, the Automated Endoscopic System for Optimal Positioning (AESOP) robotic system became the first system approved by the Food and Drug Administration (FDA) for its endoscopic surgical procedure (Lanfranco et al. 2004, Unger et al. 1994). AESOP was designed to manoeuvre an endoscope inside the patient's body during the surgery. The camera moves based on voice commands of the surgeon or through computer commands. Such versatility of the system allows for more precise movements and also allows the endoscope to be inserted into the patient through a smaller incision. ZEUS surgical system

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was a successor of AESOP system, designed to assist in the control of blunt dissectors, retractors, graspers, and stabilizers during laparoscopic and thoracoscopic surgeries (Satav 2003, Leal Ghezzi and Corleta. 2016).

A major breakthrough in the use of robots for surgical procedures was the development of the Da Vinchi Surgical (DVS) system, which was approved by FDA in 2000 (Leman and Cadiere. 1998, Hagen et al. 2014). This system was designed to facilitate complex surgery using a minimally invasive approach, and is controlled by a surgeon from a console. The latest generation of the DVS system also provides for a dual console option that allows two surgeons to work collaboratively. This facilitates more efficient training of surgeons, especially those unfamiliar with robotic-assisted surgery. The DVS system is currently used for a variety of surgical interventions: general, thoracic, cardiac, colorectal, gynaecology, urological, etc (Leal Ghezzi and Corleta. 2016).

In dentistry, Robotics is still in its infancy, even though all the necessary technologies have already been developed and could easily be adapted. In prosthodontics, the application of robots are limited mainly to the tooth arrangement in partial and complete dentures, and in dental implantology (Jiang et al. 2014). The details of the robotic systems used in such prosthodontic procedures are described below.

II. VARIOUS APPLICATIONS

A. TOOTH ARRANGEMENT ROBOT FOR COMPLETE DENTURES

The traditional way of complete denture manufacturing is manual, and the key step of the procedure is to implant artificial teeth into a tooth pad in their correct positions and orientations. Only speciality dentists and skilled technicians can do this work well. This traditional approach is now replaced with the use of robots to manufacture denture systems. Complete dentures vary considerably in tooth size, the relative position and orientation of each tooth, and the shape of the teeth arch curve. The advantage of a robot is its operational flexibility, and can be adapted for handling the manufacture of complete dentures.

CRS Robotics Corporation, Canada, produced a single manipulator robotic system with 6 DOFs. This system was then adapted for the manufacture of complete dentures (Zhang et al. 2001, Song et al. 2001). The main components of the system are (1) CRS robot, (2) electromagnetic gripper, (3) a computer, (4) a central control system with tooth-arrangement and robot control software for tooth-arrangement, motion planning and control, (5) denture base, (6) light source device, and (7) light-sensitive glue (Wang and Li. 2001). The robotic arm of the system is shown in figure 1.

Figure 1: Robotic arm of the typical CRS robot system

The three dimensional virtual tooth-arrangement software of the robotic system helps to create medical history files of a patient, draw a jaw arch and dental arch curves by expert's experience according to the jaw arch parameters of the patient, and adjust the dental arch curve. It then display the three dimensional virtual dentitions on the screen, provide a virtual observation environment for designed dentitions, and interactively modify each tooth posture. The calibration of the tooth arrangement, initial positioning of the robot, creating control data for tooth arrangement and the overall control of the robot are done by the robot control software. The maximum load this robot system can handle is 3 Kg, the maximum line velocity is 4.35 m/s, and the repeated positioning accuracy is ±0.05 mm. This system was then adapted for the manufacture of a complete denture system for patients. The system relies on the use of a special light sensitive material that hardens under lighting. In this system, a robot grasps selected standard teeth and implants them in fixed positions. However it was found that the system had difficulty in grasping and manipulating the artificial teeth accurately. This led to the development of more improved robotic systems with more number of DOFs.

Further research led to the design of an advanced 84 DOF system with 14 independent tooth manipulators on the dental arch curve (Zhang et al. 2008). In order to adjust the tooth's position on the dental arch, the manipulators were designed to move along its tail in both directions. There was a tooth arrangement helper in the system with 6 DOFs (three rotations and three movements) to adjust the tooth for its position along X, Y, Z, lingual, rotation and near-far-medium directions. This robotic system is able to realize any posture in the artificial teeth space, and solved many problems of the single robotic system. But one major disadvantage of this system is that it is driven by 84 independent motors and hence difficult to control it which reduced the efficiency.

A much improved 50 DOF tooth arrangement robotic system was then designed with 14 independent manipulators, a dental arch generator and a slipway mechanism as its components (Zhang et al. 2011, Zhang et al. 2010). Dental arch generator create the dental arch curve and matches with the one from the patient's oral cavity. The slipway mechanism is used to control the dental arch generator. As in the 84 DOF robotic system, the 14 independent manipulators are able to move along its own tail to adjust for each tooth's rotation. Each of these manipulators had 3 DOFs (two rotation and one

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movement) to adjust each tooth for its position along Z, lingual and near-far-medium directions. The additional 3 DOFs for adjusting the tooth in the X, Y and rotation are achieved by two parallel and rotatable vertical bars placed under every single manipulator. This kind of adjustment helped to decrease the number of motors required to drive the system to 50, thus increasing the efficiency of the system. Compared to previous generation systems, this 50 DOF tooth arrangement robotic system is simple and easy to control and takes only 30 minutes for the manufacture of a complete denture. The repeated positioning accuracy of the system is ± 0.07 mm for single manipulator and ±0.1 mm for the whole robotic system.

Though there are tremendous progress in improving the efficiency of the complete denture manufacturing robotic system, the procedure still remains mostly a manual operation. The high cost and lack of operational knowledge of the system are the main hindrance for the wide spread use of the system.

B. DENTAL IMPLANTOLOGY ROBOT

Applications of computer assisted pre-operative procedures like CAD/CAM are followed in dental implantology for long. But the use of robots for the surgical procedure is relatively new. Applications of robots for the implant surgical procedure was a research theme in many of the research and medical centres over the recent period. They are considered as a step forward in utilizing the applications of computer assisted pre surgical planning to the usage of robots in the surgical phase. Several prototype systems were developed in many centres like University of Kentucky, Ecole des Mines de Paris, Umea Universitet, University of Coimbra and University of Duesseldorf (Zhang et al. 2011, Pires et al. 2006).

The general features of these systems were a robotic arm with drilling tools, a data acquisition board, strain gauges for stress/strain evaluation, and a force/torque sensor (equipped with accelerometers) placed on the robot wrist (Pires et al. 2006). This system can realize drilling and implant insertion. The robot is programmed to perform the implant drilling operation with the help of a dental drilling tool and also to apply pressure on the assembled implants to simulate the mastication process. The system software consists of robot calibration module, drill plan module, load plan module, drill execution module, and acquisition data module. The optimal number of implants and their placement/orientation is studied through the implant force, and the stress/strain analysis of jaw bone tissue with the different drilling posture.

The first commercially available and state of the art robotic system for dental implantology, named as Yomi was developed by Neocis Inc, USA and approved by FDA in 2017 (U.S. Food and Drug Administration, 2017). Yomi is a computerized navigational system intended to provide assistance in both the planning (pre-operative) and the surgical (intra-operative) phases of dental implantation surgery. The system provides software to preoperatively plan dental implantation procedures and provides navigational guidance of the surgical instruments. Yomi delivers physical guidance through the use of haptic robotic technology, which constrains the drill in position, orientation, and depth. This assistive technology leaves the surgeon in control at all times. Unlike plastic surgical guides, Yomi allows for clear visualization of the surgical site and enables the surgeon to dynamically change the plan. A typical Yomi system is shown in figure 2.

Figure 2: Yomi dental implantology robotic system

In a normal implant surgical procedure, dentists can capture a pre-operative cone beam CT scan (CBCT), but much of that information is effectively lost during the most critical part of the dental implant process: intra-operative surgery. Yomi enables dentists to bridge the digital imaging pre-operatively into their operating environment through the use of haptic robotic technology. They receive real-time physical and visual guidance throughout the surgery. This provides accuracy and reliability without the need to manufacture a custom plastic guide or worry about performing an unguided freehand approach.

III. ADVANTAGES AND DISADVANTAGES

Dental robots have several advantages and disadvantages. They are

A. ADVANTAGES

- ✓ Extremely high accuracy and precision
- ✓ Stable and untiring, and hence can be used repeatedly without rest
- ✓ Able to accurately process and judge quantitative information fed into the system

B. DISADVANTAGES

- ✓ No judgment of the situation and hence unable to use any qualitative information
- ✓ Continuous monitoring of an experienced dentist is always required
- ✓ these devices still remain very expensive and out of reach of the common man

IV. CONCLUSIONS

Robotic assistance in prosthodontic applications will remain an intensively discussed topic in the coming years. Tremendous progress has been achieved in the utilizing the positive aspects of robotics for various applications of dentistry. In prosthodontics, incorporation of robots are mainly

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in the design and manufacture of complete dentures and in implantology. Use of sophisticated and specially made robots helps to improve the accuracy and precision of various prosthodontic treatments under the supervision of an expert dentist. But the human interventions cannot be completely ruled out. There's no substitute for expert skill and clinical judgment.

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